Pediatric Exercise Science, 2016, 28, 77-86
http://dx.doi.org/10.1123/pes.2015-0019

Human Kinetics
ORIGINAL RESEARCH

The Effects of 8-Week Plyometric Training on Physical Performance in Young Tennis Players

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Objectives*:** The aim of this study was to analyze the effects of an 8-week (conducted biweekly for a total of 16 sessions) plyometric training program (PT) (e.g., upper- and lower-body exercises) combined with regular tennis training on physical qualities in young tennis players. ***Design: Sixty tennis players between the ages of 12 and 13 years (age 12.5 ± 0.3 years, weight 44.2 ± 7.0 kg, height 156.6 ± 7.1 cm) were allocated to either the control group (standard in-season regimen) (CG; n = 30) or the experimental group, which received an additional PT (TG; n = 30) for 30–60 min as a substitute for some tennis training within the usual 90-min practice. ***Methods:*** Pre- and posttests included: anthropometric measures; vertical countermovement jump (CMJ); standing long jump (SLJ); 20 m sprint time (with 5 and 10 m splits); a modified 505 agility test; overhead medicine ball throw; and serve velocity test. ***Results:*** After the training intervention, the TG showed significant (p < .01) improvements in all the parameters analyzed, with percentages of change and effect sizes ranging from 3.1% to 10.1% and 0.4 (small) to 1.3 (moderate), respectively. No significant changes were observed in the CG after the training intervention. ***Conclusions:*** PT was shown as an important stimulus for enhancing explosive actions in young tennis players.

Keywords: stretch-shortening cycle, velocity, power, specificity

Tennis is an intermittent sport characterized by repeated high-intensity efforts (i.e., accelerations, decelerations, and changes of direction and strokes) during a variable period of time (i.e., on average 90 min) (15). To be competitive and successful, tennis players will need a mixture of speed, agility, and power combined with well-developed aerobic fitness (7). Players must be able to react as fast as possible to actions performed by the opponent, where reaction time, initial acceleration, and agility play an important role (37). Initial acceleration can be referred to as the first 10 m of a sprint (30), while agility can be recognized as the ability to change direction by starting and stopping quickly during points (45). Speed is the ability to achieve high velocity, and it is a manifestation of strength (i.e., explosive force: early portion of force–time curve) applied to a specific movement or technique (37). The average sprint distance performed in tennis is 4 m to 7 m in the course of a point, with an average of 4 changes of direction (7). Based on these facts, tennis players need to possess exceptional dynamism in multidirectional movements during matches. Together with explosive, short movements around the court, players are required to possess a good and powerful serve, as it is the most important stroke from a strategic standpoint (5). Moreover, due to its complexity (e.g., reliance on multiple body segments to produce power through properly timed rotations and complex coordinated muscular activations), it has received more attention in the literature

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than other strokes (40). To improve serve performance, muscle strength throughout the entire kinetic chain must be increased without affecting serve accuracy, therefore this is frequently the main target of training programs in tennis practice (40).

Many of the previously mentioned activities (e.g., strokes, sprints, changes of direction) require maximal power along with a high rate of power development, bearing in mind the short period spent on the ground to produce power, such as in sprinting or changing direction (< 100 ms) (3). Thus, almost every explosive action in tennis involves a stretch–shortening cycle (SSC) (8). During the SSC, the preactivated muscle is first stretched (eccentric action) and then shortened (concentric action). Plyometric training (PT) provides the required stimuli to train the SSC mechanism and can enhance explosive contractions in both pubertal and prepubertal populations (18). In this regard, it is thought that neural mechanisms are largely responsible for both natural and training-induced developments in the SSC function (17,18). PT seems to be a specific training method in many sports because of its emphasis on multidirectional jumping, hopping, and throwing. Thus, as previous research has shown improvements in jumping ability, agility, and strength, as well as in sport-specific performance after the introduction and implementation of PT programs (22,34,35), it would really be interesting to undertake PT programs in prepubertal periods. In this context, it is important to highlight that the effects of the PT programs might be different depending on the child's timing of maturation. Previous research (23) showed the importance of the predicted peak height velocity (PHV) and knowing whether the improvements in force, velocity, and power in youth are due to the training process or natural development during growth and maturation. Several authors agreed that the beginning of strength and power improvements occurred around 1.5 years before PHV (32), likely regulated through neurological factors, and these changes before puberty could justify natural increases in maximal power (20). Thus, youth training models have pointed out the need to stimulate intermuscular coordination, movement efficiency, and velocity before puberty rather than strength training to improve power (41).

Over the last few years, competitiveness in tennis has increased significantly, and players have devoted a great amount of time to improving their tennis skills through technical and tactical training, with an average of 15–20 hours of technical training per week, even at a young age (36). Thus, it seems reasonable to improve the previously mentioned physical qualities (e.g., jumping ability, agility) from a young age. Although muscle strength is thought to play a major role in tennis performance, a paucity of scientific consideration has been afforded to establishing an evidence base for tennis-specific strength training in light of its popular integration into current practice. Just a few studies have been conducted evaluating the effects of training programs, including PT, on tennis performance (e.g., sprint, serve velocity) in players of different ages (i.e., 13–21 years) (2,8,9,43). Moreover, it's well established that PT can constitute a safe and appropriate tool for improving explosive actions in young athletes ranging from prepubertal to late pubertal ages (17,33–35).

Therefore, although it is well established in other sports (i.e., soccer), the design of effective PT strategies seems to be important for tennis coaches and players since they can be readily implemented with minimal equipment and effort, leading to specific athletic quality enhancements. Thus, the purpose of the current study was to analyze the effects of adding an 8-week PT program (e.g., upper and lower body) as a substitute for some tennis training, within the usual 90-minute practice, on physical performance (i.e., sprinting, jumping, agility, throwing ability, and serve velocity) in young tennis players. It was hypothesized that the use of plyometric exercises instead of additional tennis training would enhance explosive actions to a greater extent than tennis training alone.

Methods

Design and Participants

This study was designed to analyze the effects of 8 weeks of biweekly (16 sessions) PT on physical performance in young tennis players. Physical tests were carried out before (pretest) and after (posttest) the training period, including (a) anthropometric measures, (b) vertical countermovement jump (CMJ), (c) standing long jump (SLJ), (d) 20 m sprint time (with 5 and 10 m splits), (e) 505 agility test, (f) overhead medicine ball throw (MBT), and (g) serve velocity test.

After pretests, 60 male tennis players between the ages of 12 and 13 years (age 12.5 ± 0.3 y, weight 44.2 ± 7.0 kg, height 156.6 ± 7.08 cm; 48 players were right-handed and 12 were left-handed) from 3 international tennis academies were assigned to either the control (standard in-season tennis training) (CG; $n = 30$) or training group, which received the additional PT (TG; $n = 30$). Due to organizational limitations in these academies, no randomization of groups was possible, although pretests were used to control the initial status of players. Inclusion criteria for all participants required each participant to have a minimum of 3 years of tennis-specific training and show no history of recent surgery, no rehabilitation for the past 12 months, and no participation in a formal strength training program during the 4 weeks before the study (i.e., just some experience, familiarization sessions) in a variety of plyometric (e.g., medicine ball, hopping) and injury prevention training (e.g., elastic tubing and core training). All the players participated, on average, in 8–10 hours of tennis training per week, focused on the development of on-court technical/tactical tennis behavior, as well as the enhancement of tennis-specific aerobic and anaerobic capabilities. The TG performed PT for 30–60 minutes as a substitute for some tennis training within the usual 90-minute practice. The CG followed their normal tennis training (3 sessions per week), in addition to 1 to 2 self-regulated moderate- to low-intensity injury prevention (e.g., core training, shoulder strengthening, and flexibility) sessions.

The TG undertook the PT program between 16:00 and 17:00 hours (in a weight training room facility) and the tennis training (Rebound Ace tennis court) from 17:20 to 18:30 hours. To ensure familiarization with the training and testing procedures, all participants completed 2 familiarization sessions (i.e., 1 h each) one week before the basal measurements (i.e., pretests). The participants were also instructed to maintain their usual dietary habits for the duration of the study. Before participating in the study, the participants were fully informed about the protocol, and written informed consent was obtained from each participant before testing as well as written informed consent from the parents/guardians. The participants were free to withdraw from the study without penalty at any time. The procedures were approved by the Institutional Ethics Review Committee (Miguel Hernandez University, Spain) in accordance with the Declaration of Helsinki.

Measures

Tests were scheduled > 48 hours after a competition or hard physical training to minimize the influence of fatigue. The assessment of the program was performed under similar weather, time, and surface conditions (Rebound Ace surface; temperature 24.4°C to 26.4°C, relative humidity 54.4% to 61.0%; Kestrel 4000 Pocket Weather Tracker, Nielsen Kellerman, Boothwyn, PA) before and immediately after the 8-week training period. All tests were administered on the same day (e.g., morning and evening session). Each player was tested in the same order and recorded by the same investigators. Investigators were blinded for group allocation during both pre- and posttesting. Before testing, players performed a standardized warm-up (i.e., 10 min including aerobic exercise, general mobilization, and ballistic exercises). In addition, care was taken to allow sufficient rest time between all tests to limit the effects of fatigue on subsequent tests.

Body height was measured with a fixed stadiometer (± 0.1 cm; Holtain Ltd., Crosswell, UK), sitting height with a purpose-built table (± 0.1 cm; Holtain Ltd., Crosswell, UK), and body mass with a digital balance (± 0.1 kg; ADE Electronic Column Scales, Hamburg, Germany), following the guidelines proposed by the International Society for the Advancement of Kinanthropometry (ISAK) (6). Pubertal timing was estimated according to the biological age of maturity of each individual using the predictive equation described by Mirwald et al. (24) (standard error of measurement [*SEM*] = 0.592). The age of peak linear growth (age at peak height velocity) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence (24). Calculating the biological age of maturity (years) was achieved by subtracting the chronological age at the time of measurement from the chronological peak-velocity age (21,44). Therefore, a maturity age of –1.0 indicates that the player was measured 1 year before this peak velocity; a maturity of 0 indicates that the player was measured at the time of this peak velocity; and a maturity age of +1.0 indicates that the participant was measured 1 year after this peak velocity (21).

Time completing a 20 m straight line dash (with 5 and 10 m split times) was accurately measured by using single-beam photocell gates placed 1.0 m above the ground level (Time It; Eleiko Sport, Halmstad, Sweden). Each sprint was initiated from an individually chosen standing position, 50 cm behind the photocell gate, which started a digital timer. Each player performed 2 maximal sprints interspersed with 3 minutes of passive recovery, and the fastest time achieved was used for the subsequent statistical analysis. The intraclass correlation coefficient (ICC) was .91 (.89–.93).

A CMJ test was performed using an electronic contact platform (Ergojump, Jyvaskyla, Finland). Participants were instructed to place their hands on their hips while performing a downward movement followed by a maximal effort vertical jump. All the subjects were then instructed to land in an upright position with the knees bent after the landing. Two trials were executed with a passive pause of 45 seconds between jumps. The highest value of the two trials was used for the subsequent statistical analysis. The ICC for this test was .95 (.93–.97).

The athlete's ability to perform a single, rapid 180° change of direction over a 5-m distance was measured by using a modified version (stationary start) of the 505 agility test (28). Players assumed a preferred foot behind the starting position and accelerated voluntarily, sprinting with maximal effort without a racquet. Two trials pivoting on both left and right foot were completed, with the respective best times recorded to the nearest 0.01 second (Time It; Eleiko Sport, Halmstad, Sweden). Three minutes of rest were allowed between trials. The ICC for this test was .92 (.90–.94).

Serve speed tests were measured by instructing players to use their preferred technique for the serve and hit a tennis ball as fast as possible into the designated area. Two experienced coaches supervised the testing procedures. The coaches elaborated a serve technique checklist (through discussions with elite coaches and biomechanists and by using information extracted from an advanced coaching manual [8,12]). The checklist included information about basic serve phases (e.g., swing [maintenance of smooth, fluid action/momentum], including racquet speed; hip and shoulder rotation [torsion/stretch]; tossing arm [height when ball released, consistent/not consistent]; and landing [change in distance of landing inside the court after impact]). Coaches were then briefed and required to perform several familiarization trials to minimize inter- and intratester variability.

A radar gun (Stalker Professional Sports Radar, Plymouth, MN) was used to measure serve speed, following the methods previously described (8). The radar was positioned on the center of the baseline, 4 m behind the server, aligned with the approximate height of ball contact (~2.2 m) and pointing down the center of the court. Players performed 8 maximum serves, all to the advantage side of the court, using their own racquet and a set of new balls for every test (Dunlop Fort All-Court, Hanau, Germany). In order for measurements to count, serves had to be in the service box. The highest speed recorded was used for the subsequent statistical analysis. The intertrial reliability for serve velocity was 3.2% and ICC = .91–.94, as found in previous research (8,12). The accuracy scores for the serves were determined by counting the number of times the ball landed within the designated target perimeter and adding up the assigned values (Figure 1). Target dimensions were designed taking into consideration similar methodologies and available resources, through discussion with coaches and athletes, and preliminary trials (12). As illustrated in Figure 1, the target area (i.e., 180 × 90 cm) for the serve was inside the intersection of the service line and the center line. Participants served from the deuce side of the court and were instructed to "serve first serves flat (hitting back of the ball at contact) and down the T" (center line). Shots landing within target areas were ranked according to a 3, 2, 1 scoring system. Balls landing outside the perimeter of the target areas (i.e., errors) received a 0 score.

An overhead MBT was set up and administered using a 2-kg ball and following the protocol outlined by Ulbricht et al. (48). The distance from the line to the point where the ball landed was measured and the best performance, between 2 efforts, was recorded to the nearest 5 cm. Thirty seconds of rest was permitted between trials. The best value of the 2 trials was used for the subsequent statistical analysis. The ICC for this test was .88 (.86–.90).

For the SLJ, players, positioning their feet together, stood behind a starting line and pushed off vigorously, jumping forward as far as possible. The distance was measured from the take-off line to the point where the back of the heel nearest to the take-off line landed on the

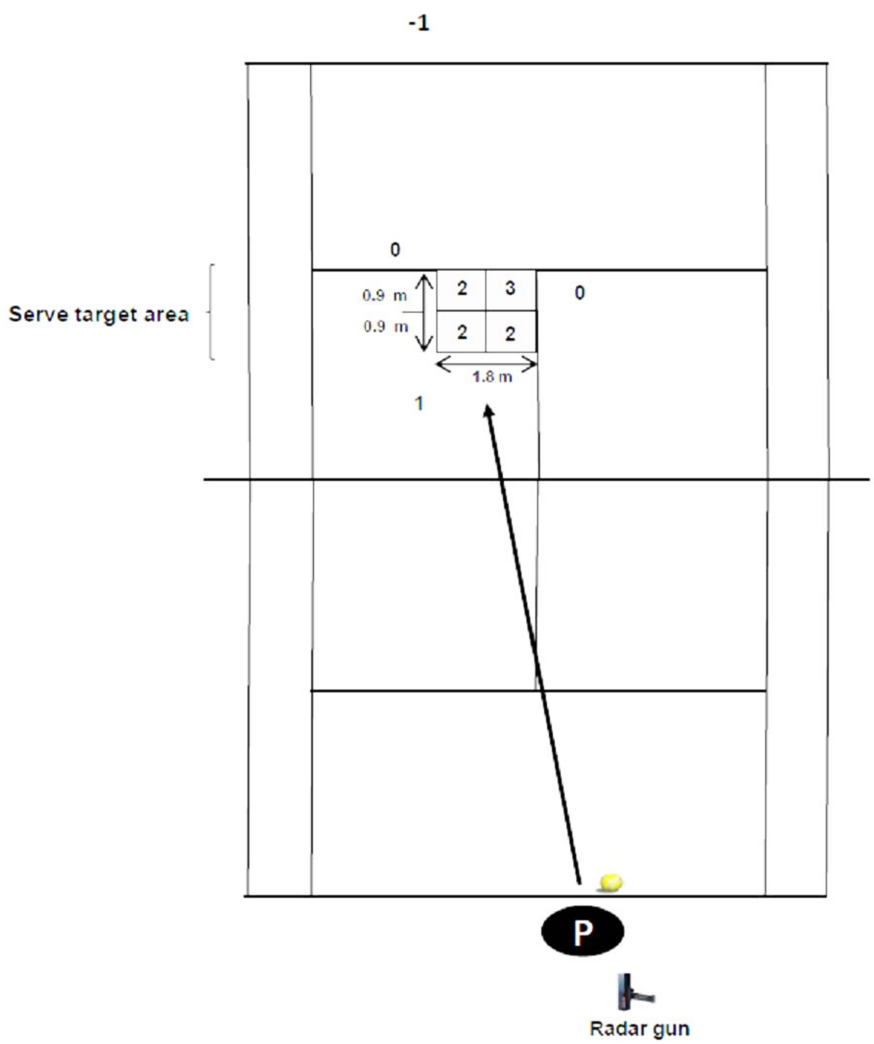

Figure 1 — A schematic representation of the serve performance test and target area dimensions. P = player.

mat or nonslippery floor. The best outcome (in cm) from the 2 trials was used for the subsequent statistical analysis (4). The ICC for this test was .78 (.75–.83).

Training Program

The plyometric training program consisted of a combination of upper body and lower body exercises (Table 1). Due to the complexity of supervising the tennis-specific training program, coaches organized weekly meetings to assign similar tennis training loads to both the TG and the CG (i.e., number of exercises, technical/tactical aims). The number of sets, repetitions, and exercises was chosen in accordance with previous studies conducted with young athletes (Table 1) (33–35). In other words, a program of 4 to 8 exercises, performed at maximal intensity, with 2 to 4 sets and 10 to 15 repetitions each was applied. The rest period ranged between 15 seconds and 90 seconds depending on the exercise and number of sets performed during the trials. Proper technique was ensured via verbal cues and demonstration by the strength and conditioning coaches. PT sessions were conducted within the tennis training sessions (i.e., as a substitute for some tennis training within the usual 90-min practice), lasted from 30 minutes to 60 minutes, and were followed by a 5-minute cool-down protocol (e.g., general mobilization).

Statistical Analyses

Descriptive statistics (mean ± *SD*) for the different variables were calculated. The ICC was used to determine the reliability of the measurements. The distribution for each variable was examined with the Kolmogorov–Smirnov normality test. Data were first analyzed using a 2-factor repeated-measures analysis of variance with 1 between-factor (training type; TG and CG) and 1 within-factor (period; baseline vs posttraining). When a significant F-value was achieved, Bonferroni post hoc procedures were performed to locate the pairwise differences between the means. Holm's correction was used to control type I and II errors. Effect sizes (ES) using Cohen's d and the 90% confidence intervals were also calculated. The scale used for interpretation was the one proposed by Rhea (38), which is specific to training research and the training status of the participants to evaluate the relative magnitude of an ES. The magnitudes of the ES were

Table 1 Description of the Plyometric Training Program

Week	Exercises (n)	Sets (n)	Reps (n)	Rest (s) (Exercises/Sets)	Lower Body Exercises	Upper Body Exercises
1	6	2	15	15 s / 90 s	2-foot ankle hop forward; 2-leg box hopping; CMJ	Chest throw*; overhead throw; close-stance throw
2	6	3	15	15 s / 90 s	CMJ; 2-leg multidirectional hurdle jumps; 2-leg zigzag over lines	Overhead throw; open-stance throw; 2-hand overhead throw with rotation
3	6	3	15	15 s / 90 s	2-leg zigzag over lines; lateral bounds + stabilization; 1-leg box hopping	2-hand overhead throw with rotation; overhead slam; close-stance throw
4	6	3	15	15 s / 90 s	CMJ; 2/1-leg multidirectional hurdle jumps; 2/1-leg zigzag over lines	Chest throw; open-stance throw; 2-hand overhead throw with rotation
5	8	4	12/15	15 s / 90 s	2/1-foot ankle hop lateral; lateral bounds + stabilization; 2-leg box hopping; CMJ	Push-ups; overhead throw; open-stance throw; 2-hand overhead throw with rotation
6	8	4	12/15	15 s / 90 s	2/1-leg zigzag over lines; lateral bounds + stabilization; 2/1-leg box hopping; 1-foot ankle hop forward	Chest throw; open-stance throw; 2-hand overhead throw with rotation; overhead slam
7	8	4	10/12	15 s / 90 s	2/1-foot ankle hop lateral; lateral bounds + stabilization; 2/1-leg multidirectional hurdle jumps; CMJ	Push-ups (clapping hands); overhead throw; Open/close-stance throw; 2-hand overhead throw with rotation
8	8	4	10/12	15 s / 90 s	CMJ; 2/1-leg multidirectional hurdle jumps; 2/1-leg zigzag over lines; 2/1-foot ankle hop forward/lateral	Chest throw; push-ups (clapping hands); 2-hand overhead throw with rotation; overhead slam

Abbreviation: CMJ = countermovement jump.

* 2-kg medicine ball throws.

considered trivial (< 0.35), small (0.35–0.80), moderate (≥0.80–1.5), or large (> 1.5). Statistical significance was accepted at an alpha level of $p \leq .05$.

Results

Six players from the TG and 3 from the CG were excluded from the final analysis due to acute injuries (i.e., ankle sprain) produced during PT (only 1 player) or during specific tennis training (8 players). In the CG, 2 players were excluded for missing more than 60% of the training sessions. No player developed an overuse syndrome as a result of the training program. Overall, players completed all training sessions, demonstrating excellent compliance with the training program. Years from PHV were –1.3 ± 0.6 (estimated age at PHV: 13.9 ± 0.5) and –1.7 ± 0.3 (age at PHV: 14.2 ± 2.1) for the TG and CG, respectively. Before and after training, no significant differences were observed between the TG and CG in height, body mass, or maturity status.

Values for all physical tests at pre- and postintervention are presented in Table 2. Before the training intervention, no significant differences were observed between the TG and CG in any of the parameters analyzed. After the training intervention, the TG showed significant ($p < .05$) improvements in all the parameters analyzed (e.g., CMJ; 5, 10, and 20 m sprint; 505 agility test; serve velocity and accuracy; SLJ; and MBT) compared with pretest values, with percentages of change and ES ranging from 3.1% to 10.1% and 0.4 (small) to 1.3 (moderate), respectively. No significant changes were observed in the CG after the training intervention. No significant differences were observed between the CG and TG groups (Table 2) after the training intervention.

Discussion

The aim of the current study was to analyze the effects of adding an 8-week PT program (e.g., upper and lower body) as a substitute for some tennis training within the usual 90-minute practice in young tennis players. The results from testing indicate that in comparison with normal tennis training, PT seems to be an appropriate stimulus for improving physical qualities in tennis players. Moreover, no significant changes in any test variables were observed in the CG, demonstrating the importance of specific power training for enhancing the explosive actions of tennis players.

Muscle strength/power in the upper/lower extremities is important to produce explosive actions in tennis (e.g., serve motion, accelerations, changes of direction) (10,39). In the current study, jumping performance was improved by 6.3% (small ES) in the CMJ and 8.4% (moderate ES) in the SLJ after 8 weeks of PT. Only a few previous studies analyzed the effects of PT programs on physical qualities (including jumps) in tennis players. Salonikidis and Zafeiridis (43) analyzed the effects of 3 training programs, including PT, in novice tennis players (age = 21 y), reporting a significant improvement in drop jump (DJ; 15%) and lower extremity maximum isometric force (11%) after 8 weeks of training (e.g., 3 training sessions per week). With a PT of the same duration and

Table 2 Performance Variables at Baseline and at Posttests for the Training Group and Control Group

	Training Group (n = 24)				Control Group (n = 27)			
	Baseline	Post	% of Change	ES (90%CI)	Baseline	Post	% of Change	ES (90%CI)
CMJ (cm)	30.1 ± 4.3	32.0 ± 4.1*	6.3	0.46 (–0.90;0.00)	30.3 ± 4.3	30.9 ± 4.0	1.9	0.14 (–0.58;0.31)
5 m (s)	1.17 ± 0.1	1.11 ± 0.1*	–5.1	0.97 (0.49;1.42)	1.16 ± 0.1	1.15 ± 0.1	–0.8	0.07 (–0.38;0.51)
10 m (s)	2.01 ± 0.1	1.93 ± 0.1*	–3.9	0.87 (0.39;1.32)	2.00 ± 0.1	1.99 ± 0.1	–0.5	0.11 (–0.33;0.56)
20 m (s)	3.54 ± 0.2	3.41 ± 0.2*	–3.6	0.73 (0.26;1.18)	3.54 ± 0.2	3.53 ± 0.1	–0.2	0.12 (–0.32;0.57)
505 (s)	2.95 ± 0.2	2.86 ± 0.2*	–3.1	0.58 (0.12;1.03)	2.93 ± 0.1	2.92 ± 0.1	–0.3	0.05 (–0.40;0.50)
SV (km·h^{-1})	138.6 ± 8.2	147.3 ± 14.0*	6.2	–0.79 (–1.24;–0.31)	140.1 ± 9.4	141 ± 7.8	0.6	–0.1 (–0.54;–0.35)
Accuracy (points)	11.4 ± 2.5	12.5 ± 2.4*	9.6	–0.46 (–0.91;–0.01)	11.0 ± 2.0	11.4 ± 2.3	3.6	–0.23 (–0.67;0.22)
SLJ (cm)	184 ± 11.7	200 ± 17.3*	8.4	–1.08 (–1.54;–0.59)	190 ± 13.5	190 ± 12.1	0	0.00 (–0.45;0.44)
MBT (cm)	626 ± 91.6	680 ± 114*	8.5	–0.52 (–0.97;–0.06)	604 ± 95.0	607 ± 95.0	0.4	–0.02 (–0.47;0.42)

Abbreviations: CMJ = countermovement jump; 505 = modified agility test; SV = serve velocity; SLJ = standing long jump; MBT = overhead medicine ball throw; ES = effect size; CI = confidence interval.

Note. Values are reported as mean ± *SD*.

* Significant differences between baseline and posttraining values ($p < .05$).

frequency (9) as in the current study, young (age = 17 y) tennis players improved CMJ performance by 2.2%. Comparisons are difficult since previous studies were conducted with mature players (9,43), and also because training programs were not focused exclusively on PT (9), although the present values are in accordance with previous research and show that after PT, gains in CMJ could range between 4.7% and 15% in young athletes (1,46).

With regard to the SLJ, Markovic and Mikulic (19) stated that PT could increase horizontal jumping performance by 1.4% to 7%, with less improvement than vertical jumping. In the current study, however, increases in the SLJ were higher than in CMJ (8.4% vs 6.3%), which might be explained by having a combination of lateral, horizontal, and vertical direction drills, in contrast to previous studies, in which the amount of vertical direction drills was higher (31). The improved performance observed in the jump tests was probably because of an improvement in various neuromuscular adaptations, such as increased neural drive to the agonist muscles, intermuscular coordination in the lower limb (e.g., quadriceps and calf muscles), and SSC efficiency, together with a better synchronization of body segments (17,18). These adaptations could also be linked to the interaction of growth and maturation, as it has been suggested that an adolescent performance spurt in strength and power development occurs about 1.5 years before PHV (e.g., our players: 1.3 ± 0.6 pre-PHV) and peaks approximately 0.5–1.0 years after PHV (32), as recently reported by Meylan et al. (23). However, because no physiological measurements were taken (e.g., electromyography, muscle stiffness), only speculations are possible, and the underlying adaptations induced by the PT remain hypothetical.

The results obtained in the CG showed that tennis training alone (including a similar amount of tennis training instead of PT) did not lead to significant changes in the physical qualities, including jumping performance (i.e., CMJ, SLJ), of tennis players, which is in line with a previous study using a combined training program (PT and repeated sprints) (9). Surprisingly, CMJ values in the CG showed a small increase (1.9%), which could be related to incidental increases in muscular recruitment for the legs (i.e., basically in the nondominant leg) given the repeated eccentric loading of the landing foot during the serve (28). In this regard, it has been reported that lower body power can be maintained during competitive periods (i.e., a 4-week tour) in high-level junior players (17 y) (28,29), although it will obviously depend on the training loads, not only during the competitive periods (i.e., number of matches played), but also during the precompetitive period.

As previously mentioned, speed in tennis comprises the ability to move at high velocity in different directions around the court (7,15), with initial acceleration as a key component of performance, as most tennis movements are within a 3 to 4 m radius and there is rarely a chance for players to reach maximum speed (28,37). In the last few years, a great deal of research has focused on the development of sprint performance in young athletes using a myriad of training methods (42), highlighting PT as one of the most useful training methods for speed improvements in pre-PHV athletes (11–15 y in girls, 12–16 y in boys). The present results showed that, after the PT, the TG showed a significant time reduction in all sprint tests (i.e., 5–20 m) ranging from 3.6% to 5.1%, and a small to moderate ES (0.6–0.8). These results are in line with previous studies conducted with older tennis players (17–21 y) finding significant time reductions during short sprints (i.e., 4–20 m) of ~2% to 8% after a PT intervention (44), or a combined program (PT and repeated sprints) (9). Changes in sprint performance are also in the range of previous studies conducted with young athletes, showing average time reductions of ~3% after PT programs (14,22,26). It seems that children who are pre-PHV benefit most from training that has a primarily neural basis, which can be done with PT (18,23). The combination of multidirectional jumps, including horizontal displacement, could lead to an increase in horizontal acceleration (35). Moreover, the contact times during the initial acceleration phase of a sprint are similar to those of the PT exercises employed, which may explain the greatest transfer to the acceleration phase (i.e., neural adaptations) (33). Moreover, PT may also help to induce positive changes in the tendon cross-sectional area and intrinsic properties of the muscle and tendon during this period of maturation, leading to altered ground reaction forces, therefore increasing stride length (50) and ultimately increasing running speed (42). Posttests showed no changes in sprint performance in the CG, which could be related to the lack of sufficient training stimuli, as due to the court size and movement characteristics during tennis play, players are seldom exposed to such sprint distances (> 5–10 m) (27,28).

With regard to agility, the 505 modified agility test (i.e., 2–3 s) more closely resembles the duration and movement intensity of an acute end-range stroke and midcourt recovery (2–4 s) as well as the typical movements in tennis training and match play (28). After the PT, the TG improved their performance in the agility test by 3.1%, with a small ES (0.4). Comparisons are difficult since no studies have analyzed the effects of PT on agility in tennis players. Moreover, previous studies in early and pubertal athletes (e.g., soccer players) used different agility tests, with large differences (i.e., lasting from 7 s to 19 s over distances ranging from 40 m to 50 m) (22,46). These large differences in test selection did not allow comparison with the current study. The significant change in agility time performance could be related to the PT used, as exercises contained powerful multidirectional movements, which had an impact on the capacity to change direction faster (46). This may have improved the eccentric strength of the lower limb, enabling the players to switch between deceleration and acceleration movements, which is essential for the 505 test performance (3).

The importance of the serve in tennis players has not been questioned (5,40), and increasing its mean velocity seems to be a favorable training goal when planning conditioning programs for young tennis players (2). However, information about the effects of different strength training programs on serve performance is limited (16,25,47), and there are just a few studies regarding young tennis players (2,8). The results of the current study showed that the PT program led to significant improvements in the serve velocity (6.2%) and MBT (8.5%), with small to moderate ES (0.5 and 1.1, respectively), while no changes occurred in the CG. Comparisons with previous studies are difficult since there are several important differences related to age groups (college tennis vs younger players), the duration of training, the method of training (isotonic compared with isokinetic), or the intensity of training sessions. In this regard, previous studies conducted with young tennis players reported significant improvements in the serve velocity (4–5%) after training interventions, including PT or combined strength training (e.g., core stability, elastic tubing, and plyometric [i.e., MBT] exercises) (2,8). It seems that the use of explosive exercises (e.g., upper body PT) performed at relatively high speeds, compared with classical strength training using free weights or machines, but with greater force than that used during normal sport competition (13), elicits movement-specific adaptations with an increased amount of specific angular velocity from the proximal to the distal body segments until the release of the ball. This is supported by previous research reporting significant improvements (10–20%) in strength and power variables of the upper body (e.g., shoulders) as well as in rotational strength of the trunk and hip muscles after performing medicine ball training in handball (13). Moreover, as the serve motion is a complex stroke, involving a summation of forces sequenced in a largely proximal to distal (legs, trunk, and arm/racquet) fashion (5), the critical factors in serve velocity are a transfer of power from the lower to the upper body and then to the ball (49). Thus, it seems that the present PT program possibly enhanced intermuscular coordination, resulting in an improved force transfer through the kinetic chain.

Interestingly, the PT program used here led to significant changes in the serve accuracy of the TG (9.6%; ES = 0.4). Just one previous study analyzed the effects of a PT program on serve precision in young tennis players (2), finding no positive or negative effects on this parameter. Comparisons here are difficult as serve velocity/accuracy tests are different in previous studies. We could speculate that the improvement in the kinetic chain due to the power gains after the PT (i.e., serve velocity, jumps, MBT) would help to stabilize the player from a technical point of view, and therefore to obtain a better score in the accuracy test. However, we must highlight some important methodological limitations of the present serve test. For example, accuracy should be calculated by the radial error of the ball's bounce, using video digitalization (11), and thus, test validity seems to be affected. Further investigations are needed to clarify the association between training-induced improvements of service velocity and accuracy.

Conclusions

The results of the current study showed that the addition of PT to regular tennis training seems to be an appropriate stimulus for improving physical qualities in young tennis players compared with normal tennis training alone, demonstrating the importance of specific power training for enhancing explosive actions in tennis. Some methodological limitations exist in the current study and need to be addressed. Our findings were limited to one particular group of players, and future studies should extend these observations to girls, other age groups, and other competitive levels. Further observations are also needed regarding different intensities and volumes of PT to determine the optimum dosage for this training method. Moreover, as PT was performed instead of some regular tennis training, it seems that the TG performed relatively little tennis-specific training (i.e., 30 min of a 90-min practice) and, therefore, one can expect that tennis skill performance could be affected. More studies would be therefore necessary, analyzing tennis skills (i.e., kinematic analyses of strokes) and competitive performance. Finally, we did not quantify the neuromuscular changes after PT (e.g., EMG, ultrasound analysis), and such methods should be used in further studies to provide a better understanding of the adaptations induced by PT in young athletes.

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